TUIDCC005: ERL recirculation optics for MESA

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PRISMA Cluster of Excellence
Precision Physics, Fundamental Interactions and Structure of Matter

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MESA layout and operation modes

- External beam operation
- ERL operation

MESA recirculation optics

Acceleration in isochronous and non-isochronous operation

Summary and Outlook

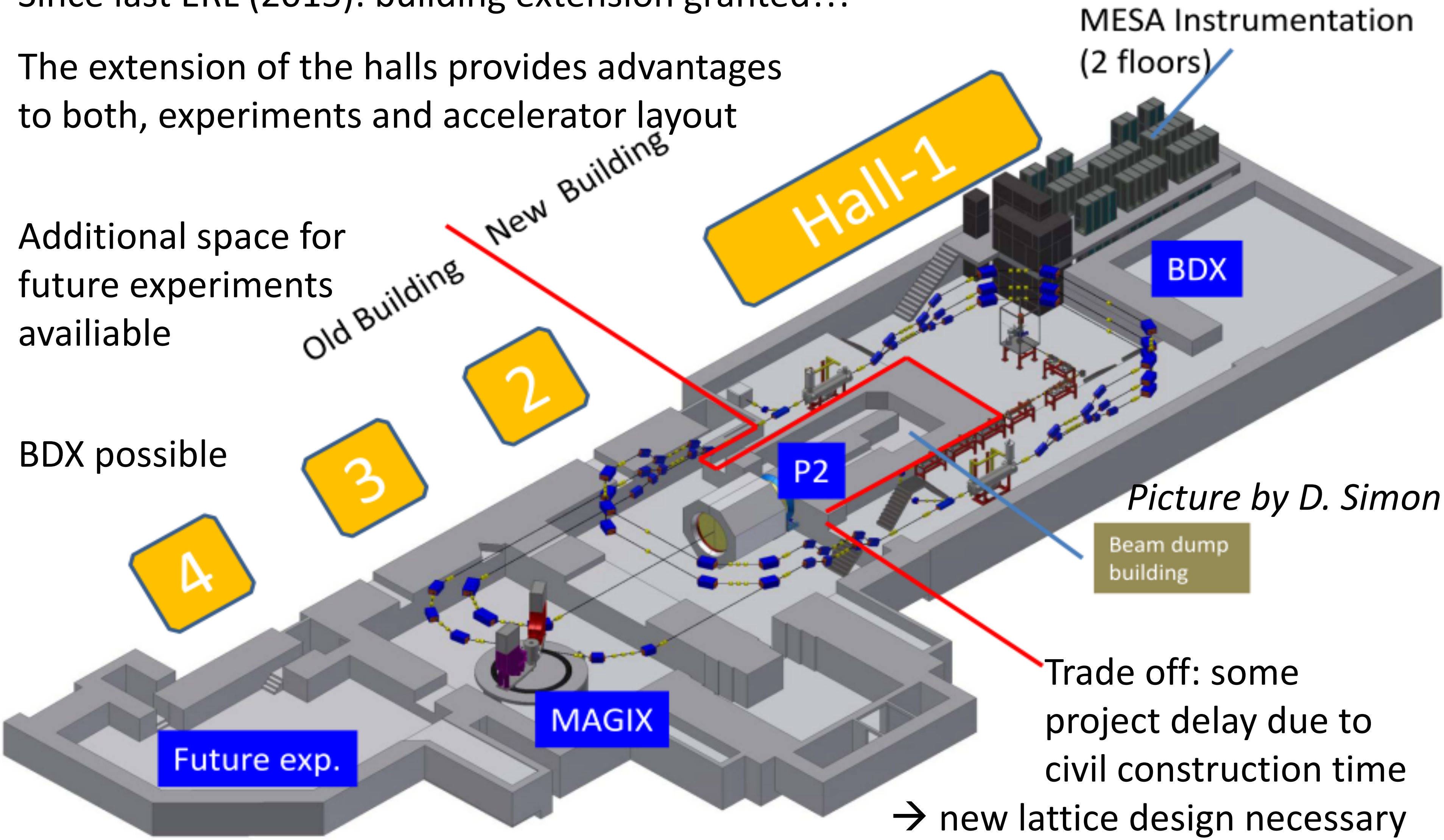
MESA accelerator layout

Since last ERL (2015): building extension granted!!!

The extension of the halls provides advantages to both, experiments and accelerator layout

Additional space for future experiments availiable

BDX possible

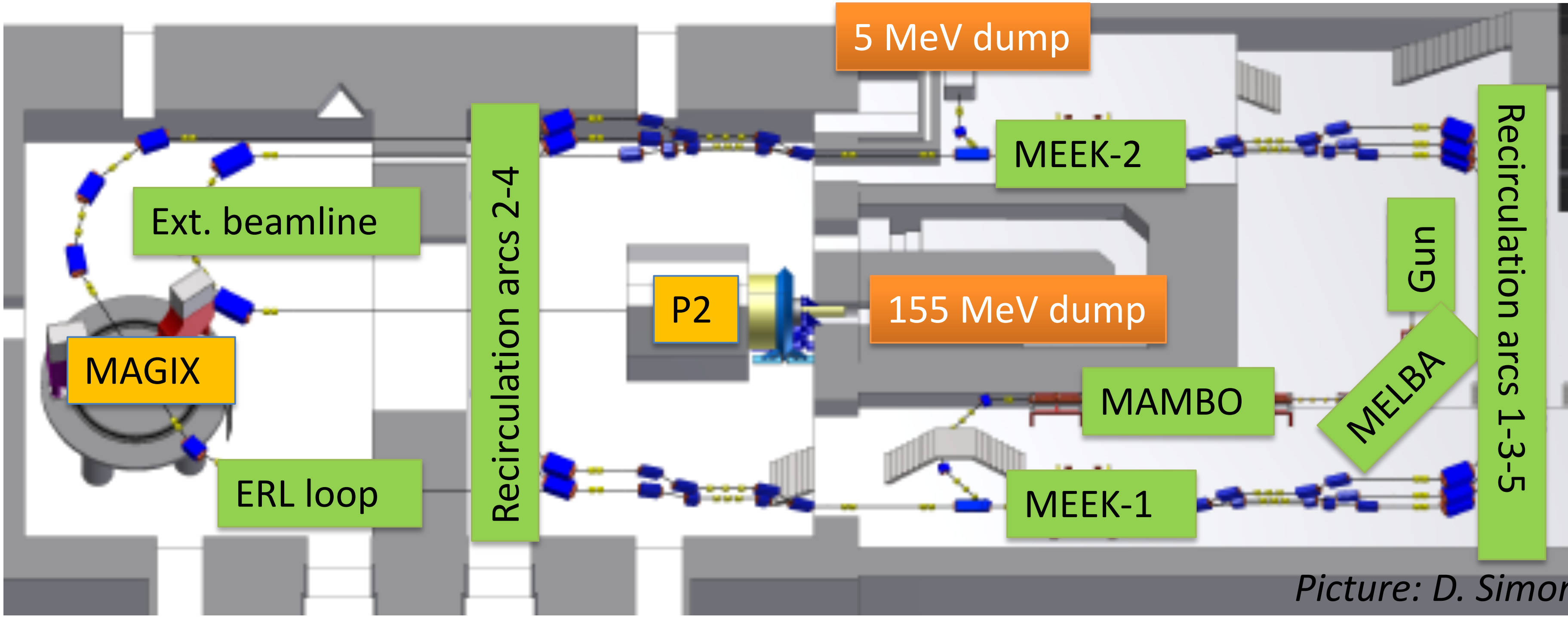


Picture by D. Simon

Trade off: some project delay due to civil construction time

→ new lattice design necessary

MESA accelerator layout



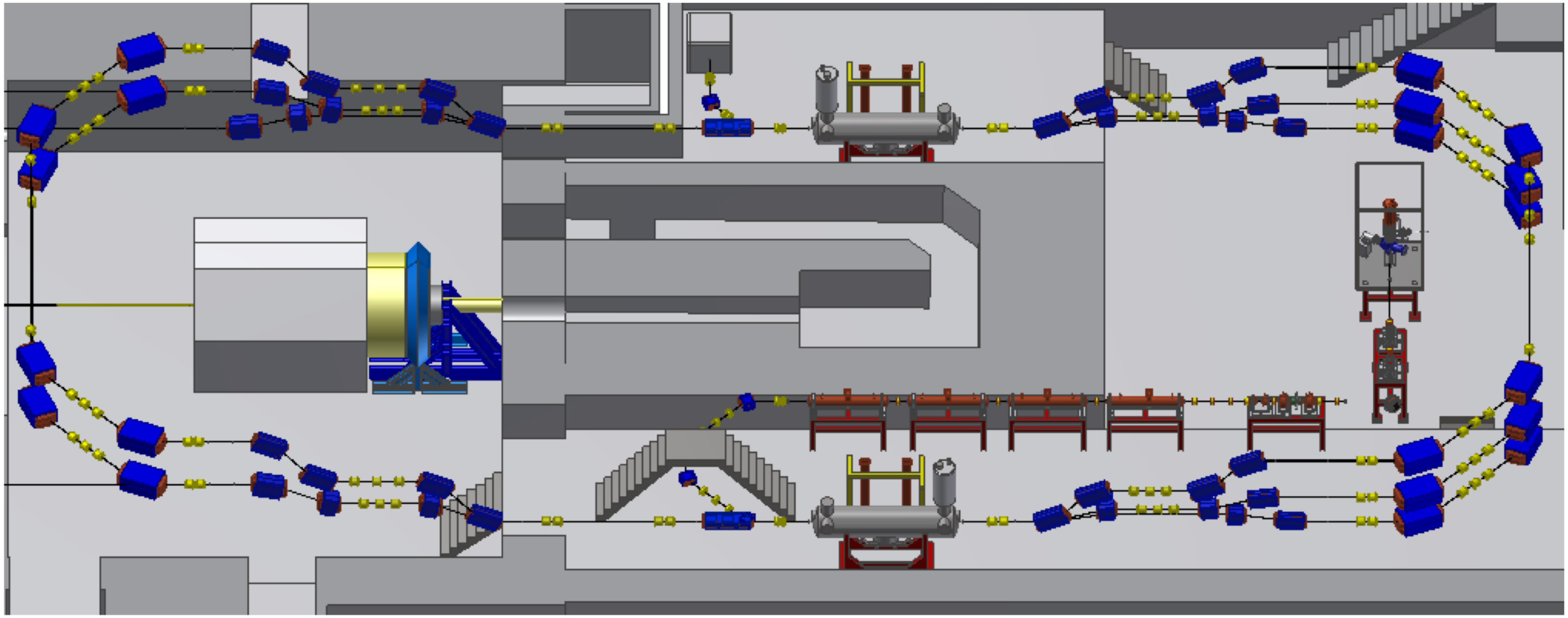
- Normalconducting injector and superconducting main linacs
- Double sided recirculation design with vertically stacked return loops
- Two modes of operation:

- EB-operation (P2/BDX experiment): polarized beam, up to 150 µA @ 155 MeV
- ERL-operation (MAGIX experiment): (un)polarized beam, up to 1 (10) mA @ 105 MeV

Challenges on recirculation lattice layout

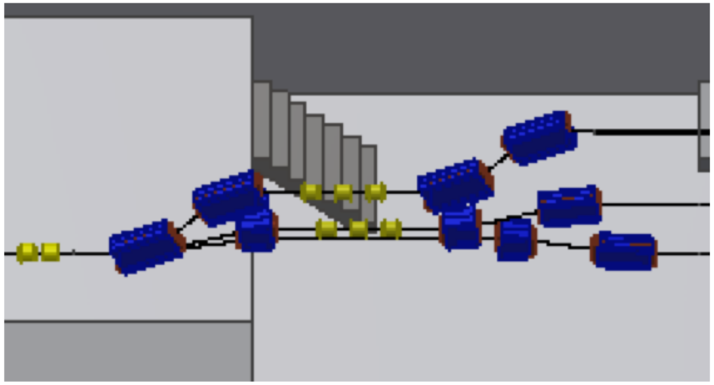
- Different operation modes require different settings of longitudinal dispersion r_{56}
  → flexibility in r_{56} without increasing transverse dispersion
- Experiments demand different beam energies, so MESA will not run on a fixed setting
  → path length adjustment needed
  → optimization of different settings during operation
- Vertical beam separation of last turn has a different focussing plane than first two turns
  → small β-functions in cryomodules in ERL mode possible (for reducing transverse BBU)
  → in EB mode less focussing on straight sections
- High demands on energy spread and beam stability by experiments

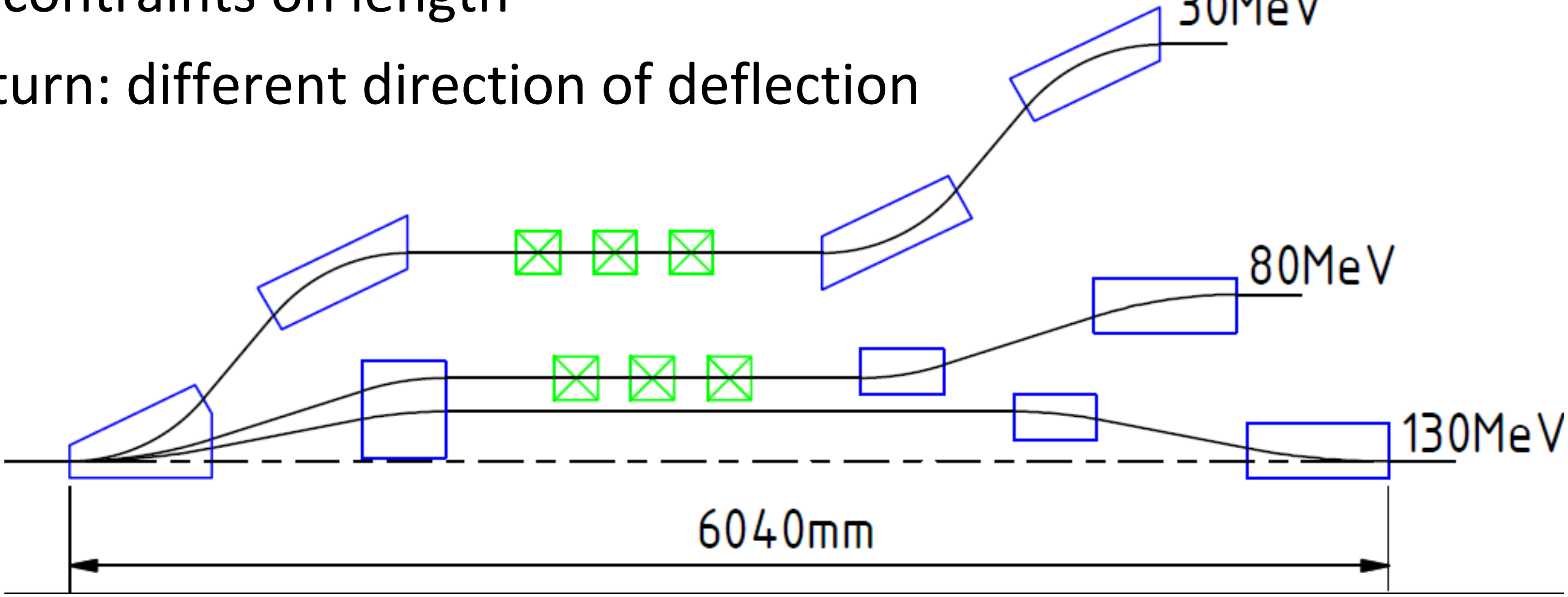
- Lattice is modelled with:
  - in house matrix optics program
  - MAD X
  - PARMELA for space charge and pseudo damping due to main linac modules
  - MATLAB tracking code for non-isochronous working points



Vertical spreaders

- Vertical spreaders separate/combine up to three beams of different energies (here: combiner before 2nd cryomodule)
- Vertical dispersion needs to be equal zero after chicane
- High contraints on length
- Last turn: different direction of deflection





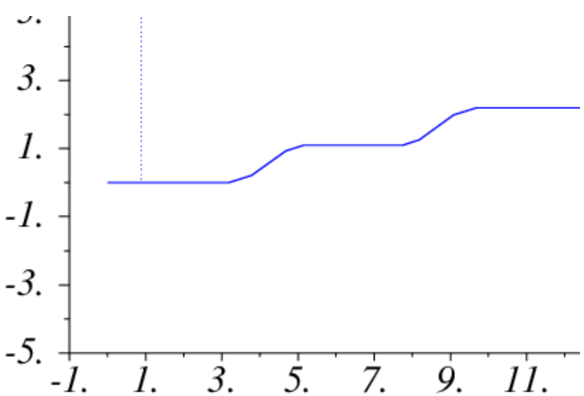
D. Simon IPAC 2015

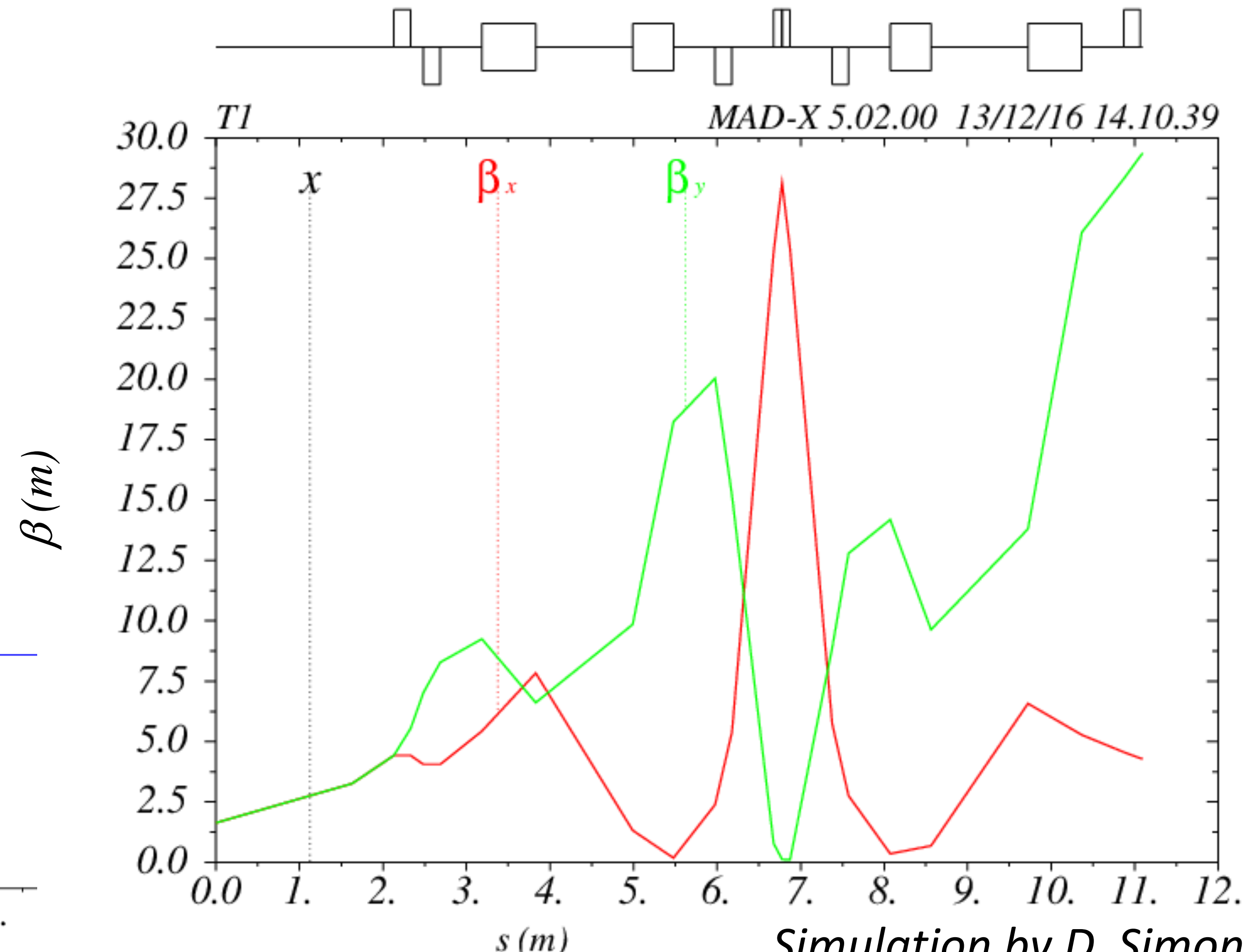
Vertical spreaders

Spreader optics for ERL operation with low β-functions on straight section

Here: 30 MeV beam

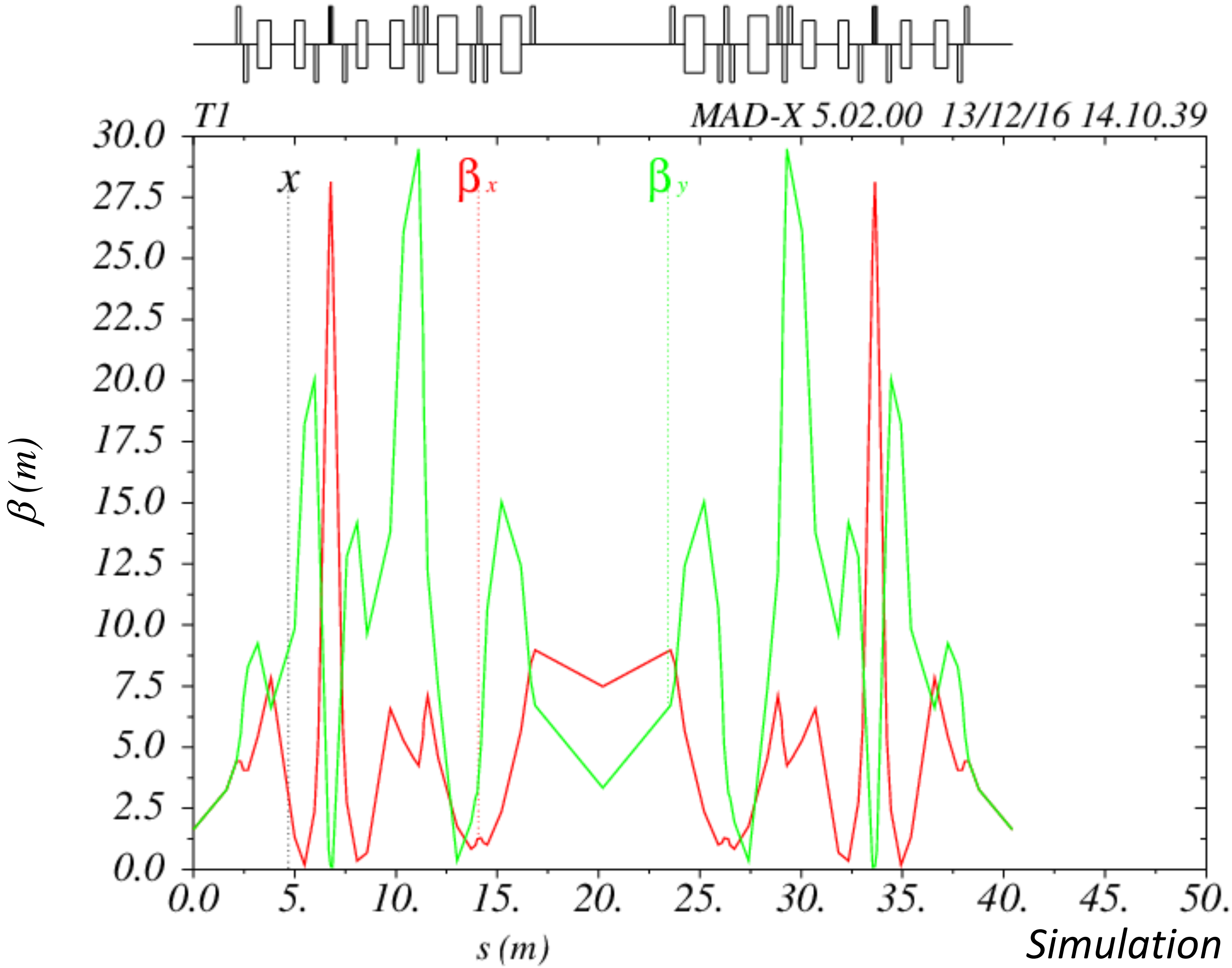
Vertical profile:





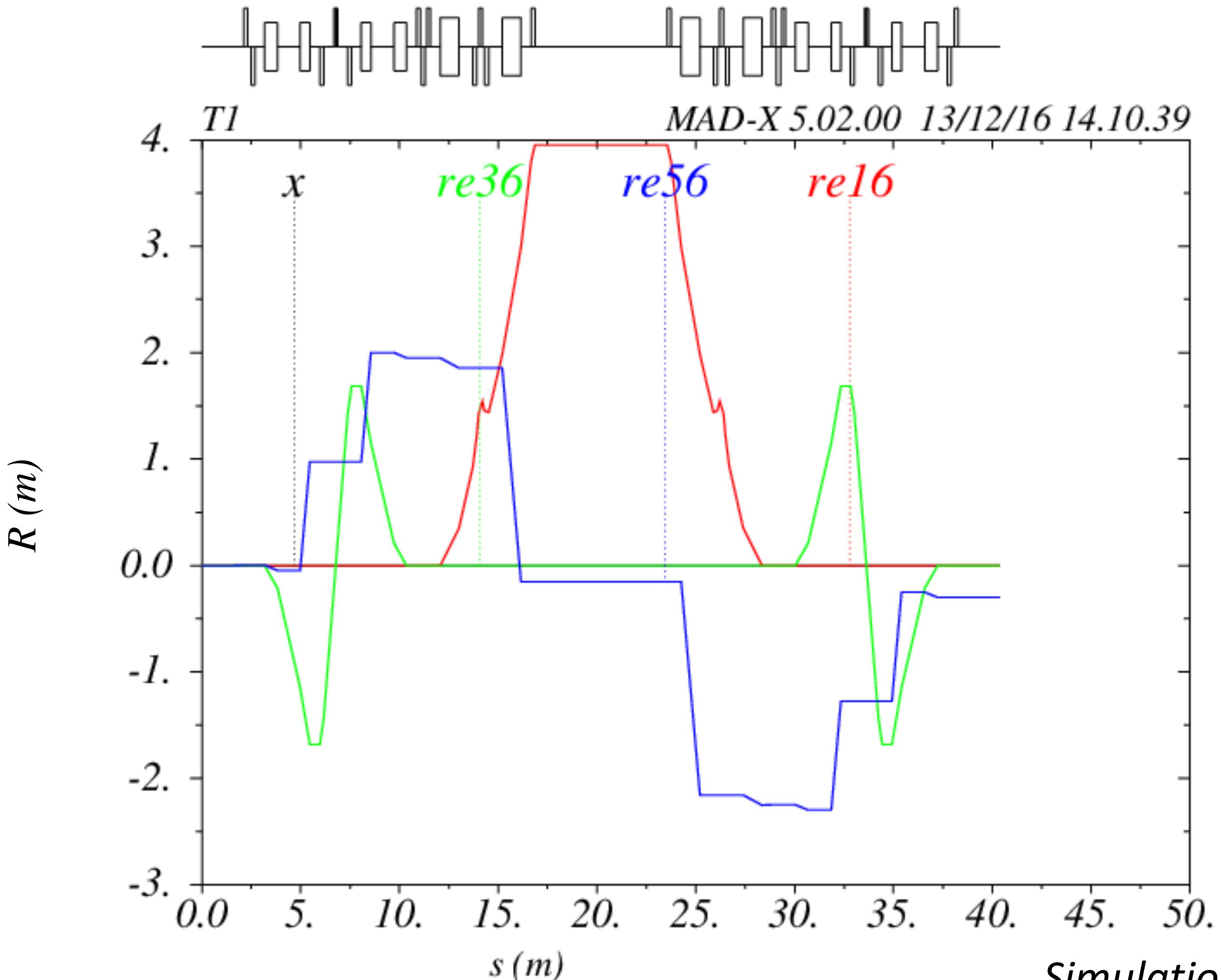
Simulation by D. Simon

Complete 1st recirculation arc lattice



Simulation by D. Simon

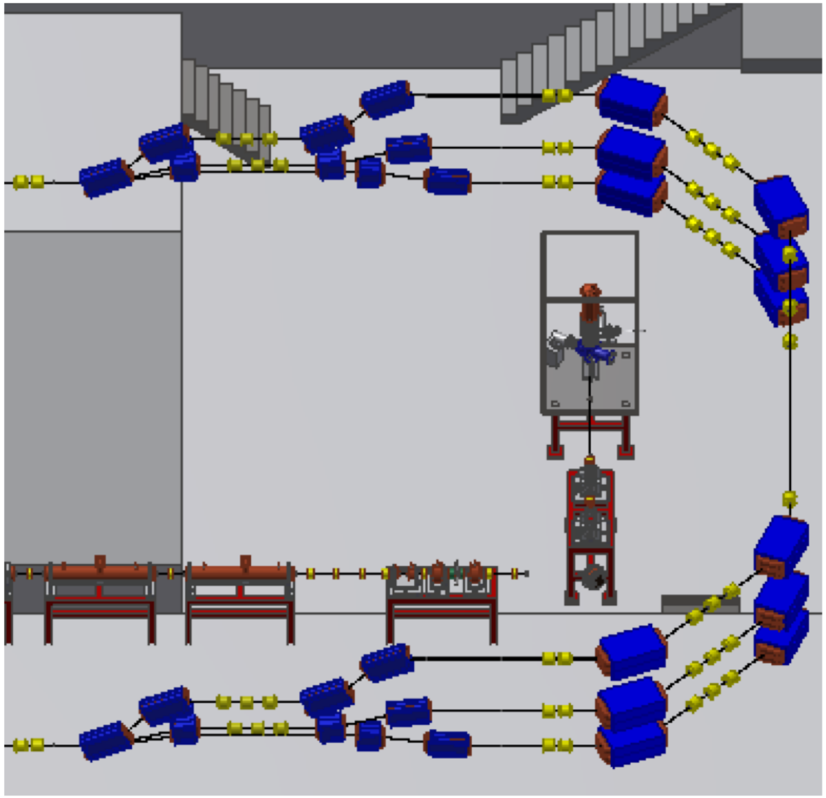
Complete 1st recirculation arc lattice



Simulation by D. Simon

Recirculation arcs optics

- Optics symmetric with respect to the middle of the long straight section. α=0 in the middle of the return arc
- Return arc is free of transverse and vertical dispersion
- Longitudinal dispersion r_{56} can be adjusted by changing the gradients of the middle quadrupoles in the 45° sections
- Total length of 1st return arc: ~45m difference in time-of-flight for beams of 15 MeV and 30 MeV: Δt=60.5 ps → 2.83° in RF @ 1.3 GHz
- Path length adjustment needed (2 cm minimum) for complete flexibility in beam energy (chicane or moveable magnets)



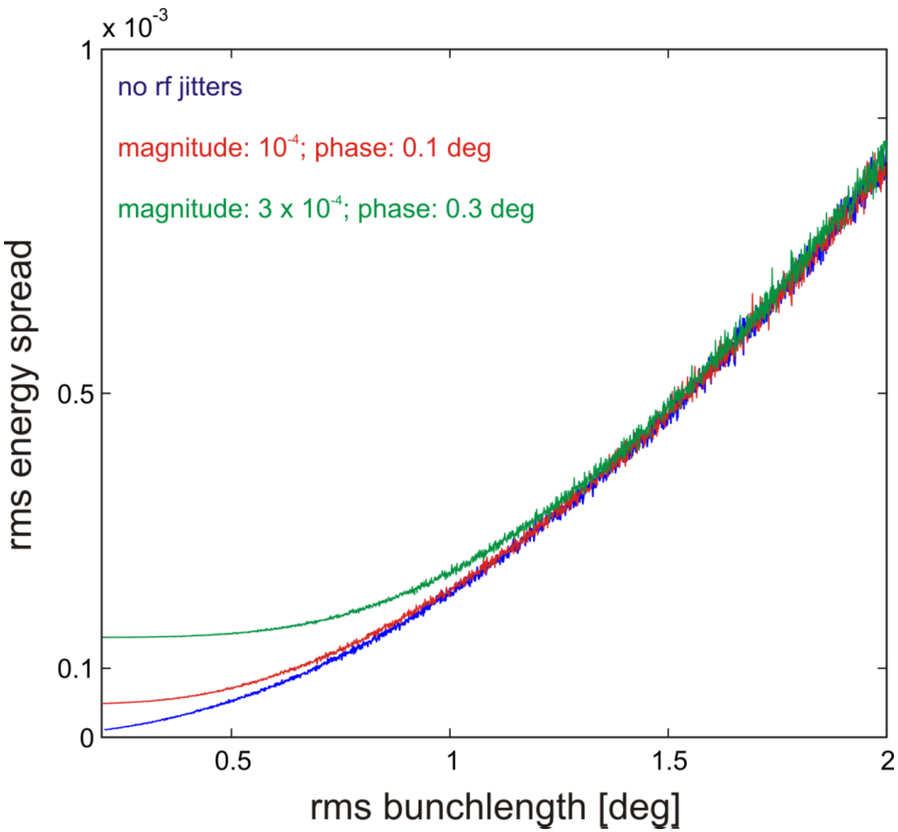
Acceleration in electron linacs

For relativistic electrons (v≈c):
almost no changes
in longitudinal position within bunch

Acceleration on crest of the rf-wave:

→ Short bunches needed because bunchlength causes energy spread!

→ Particles stay “frozen” at their longitudinal position within the bunch



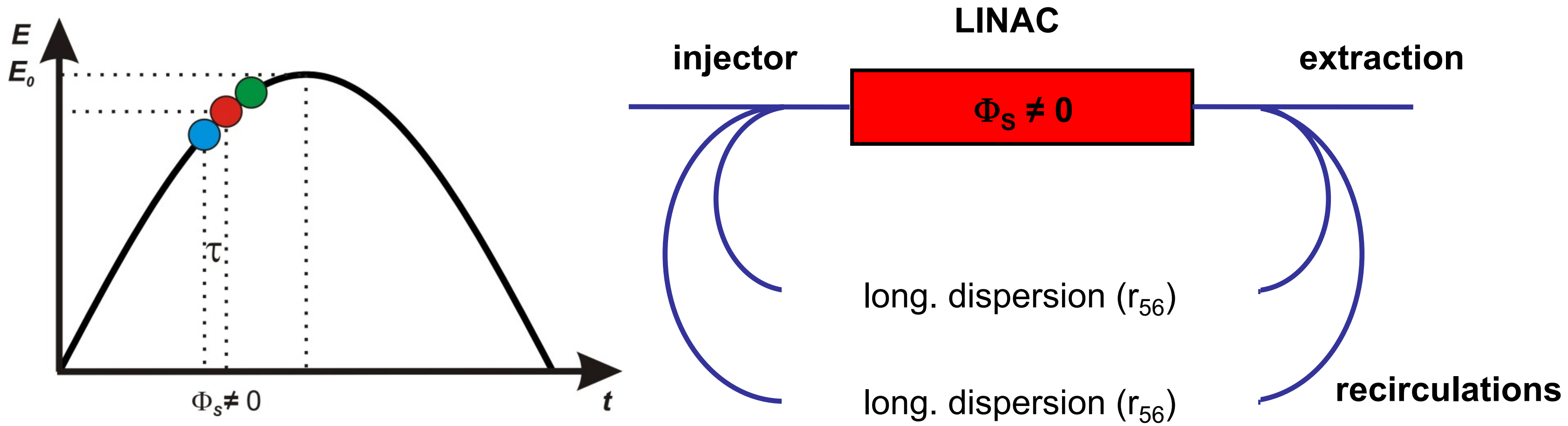
→ + additional errors from phase and amplitude jitters of the rf-system:

$$\sqrt{\left(\frac{\Delta E_{max}}{E_{max}}\right)^2 + (1 - cos\Delta\varphi)^2} < \left(\frac{\Delta E}{E_{max}}\right)_{cavity,rms} < \left|\frac{\Delta E_{max}}{E_{max}}\right| + |1 - cos\Delta\varphi|$$

(M. Konrad, PhD thesis, TU Darmstadt 2013)

Non-isochronous recirculation scheme

- Common operation mode for microtrons and synchrotrons
- Acceleration off crest of RF field
- Different time of flight for particles having different energies

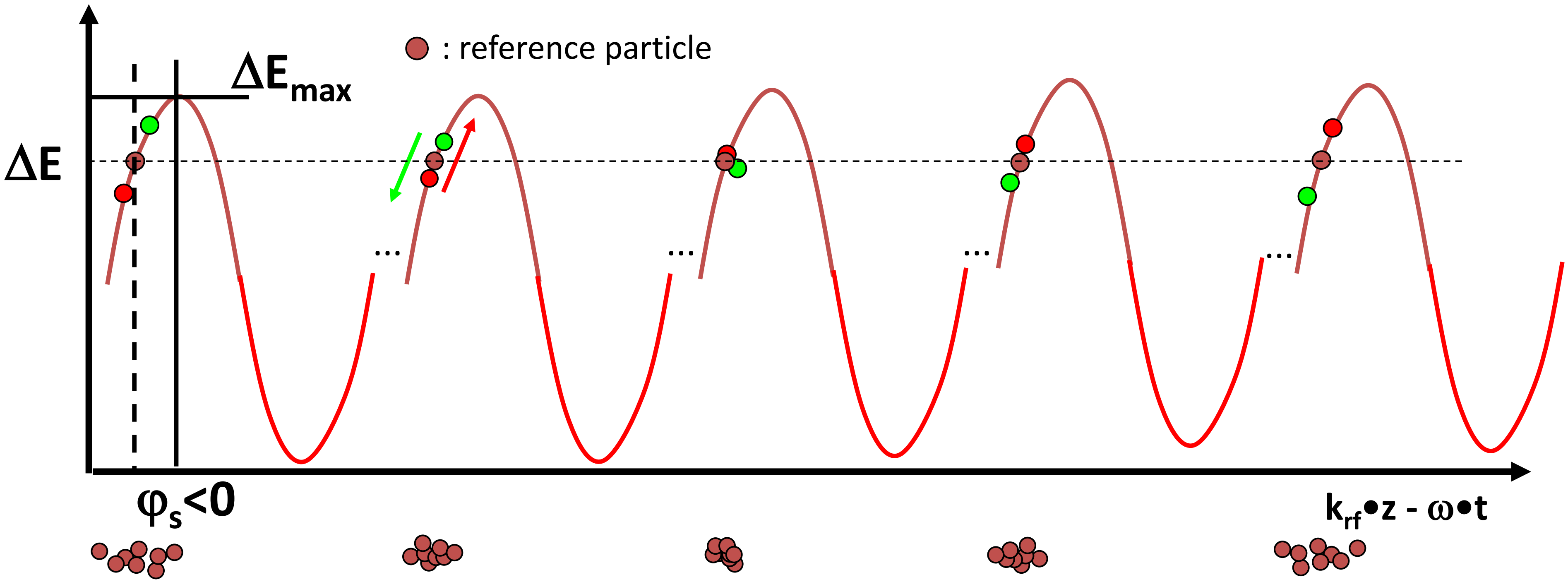


→ Particles perform synchrotron oscillations in longitudinal phase space

Half- or full integer oscillations lead to reproduction of the longitudinal phase space at injection [*Herminghaus, NIM A 305 (1991) 1*].

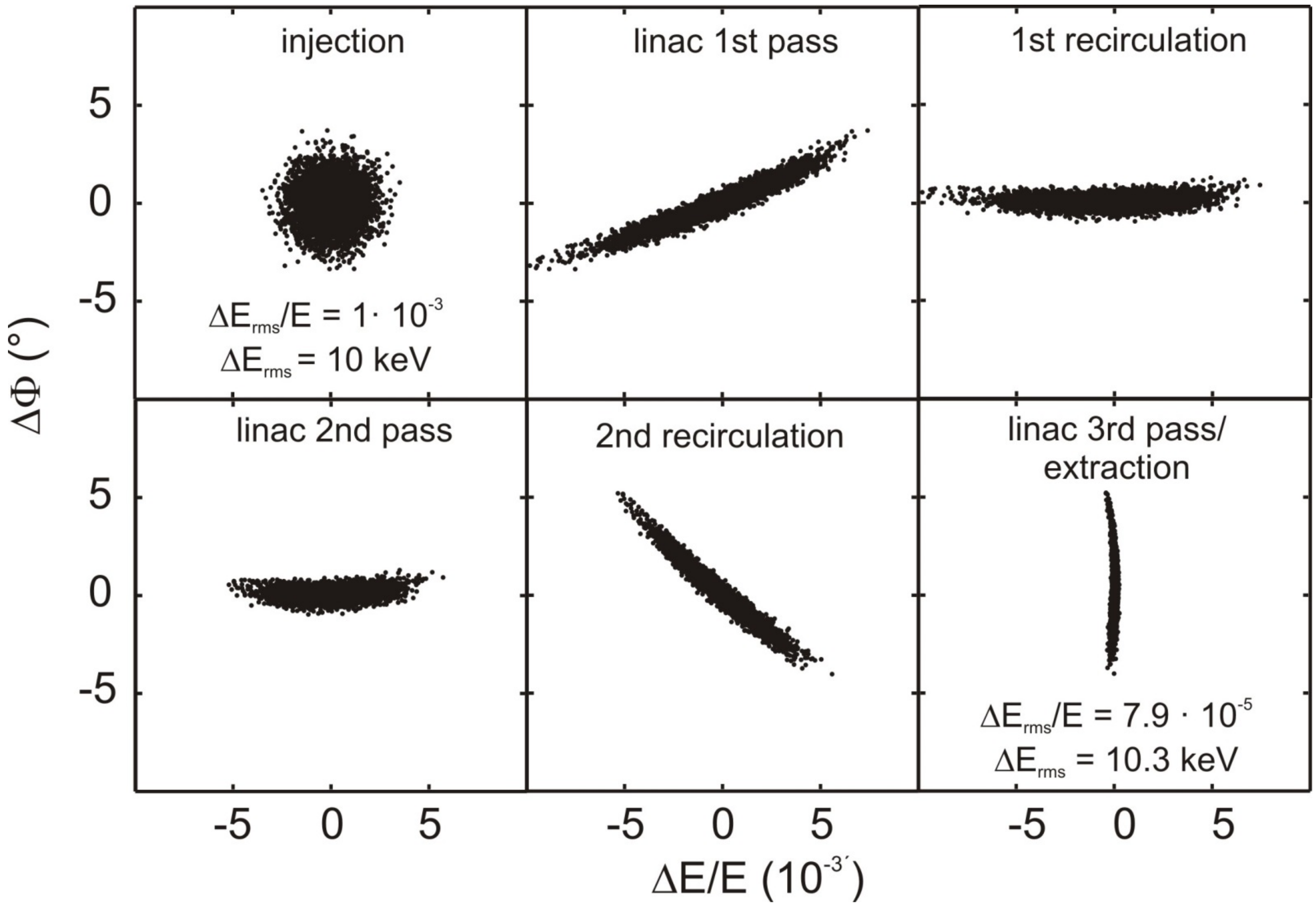
→ complete compensation of any RF phase- and amplitude jitters possible

Non-isochronous recirculation scheme



(Jankowiak/Aulenbacher, lecture on accelerator physics)

Example: non-isochronous working point of 3-pass S-DALINAC



Compare with assumption (no additional errors from linac):

Energy spread at Injection (10 MeV):

$\Delta E_{I;rms}/E_I = 1 \cdot 10^{-3}$

$\Delta E_{I;rms} = 10$ keV

After acceleration to full energy (130 MeV):

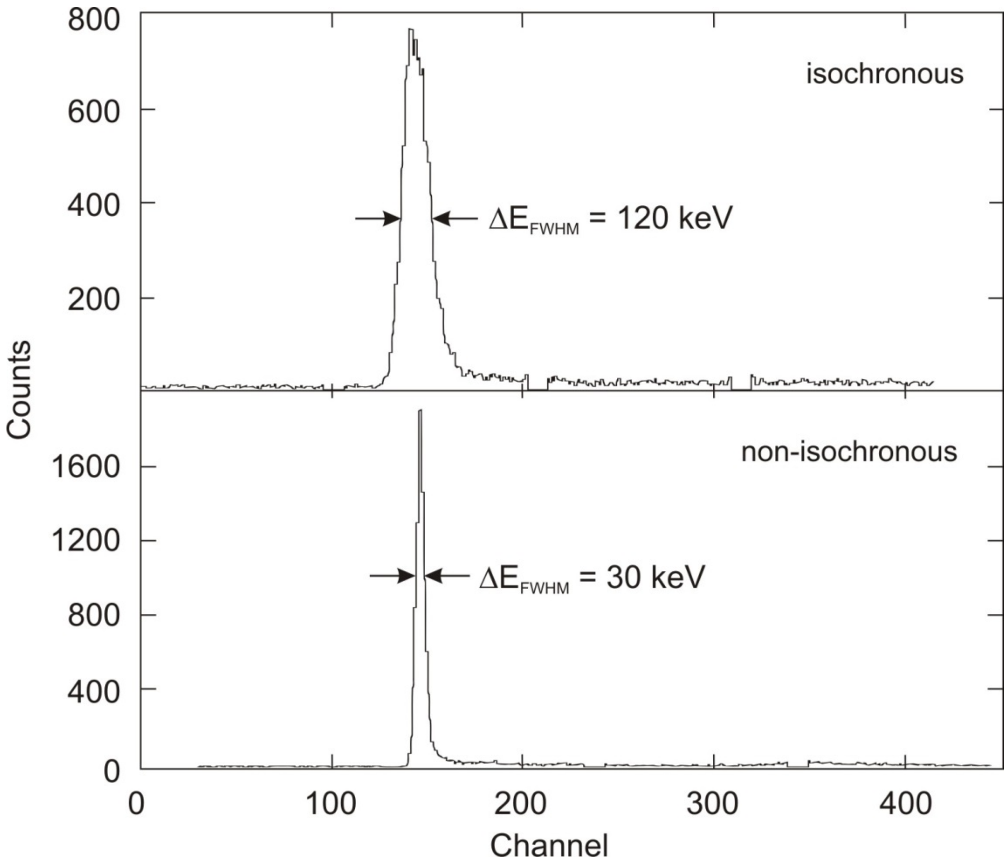
$\Delta E_{rms}/E =$

10 keV/130 MeV =

$7.7 \cdot 10^{-5}$

Resulting energy spread

Elastic scattering (e,e) at ^{197}Au in Lintott-electron-spectrometer (



→ ΔE_{FWHM} of elastic line decreased by a factor of 4

→ Energy spread of the beam decreased by a Faktor of 5.4 ($\Delta E_{rms}/E = 1,23 \cdot 10^{-4}$)

→ Highest ever achieved accuracy of a recirculated electron beam at the S-DALINAC

→ non-isochronous setting

Simulations for a new longitudinal working point

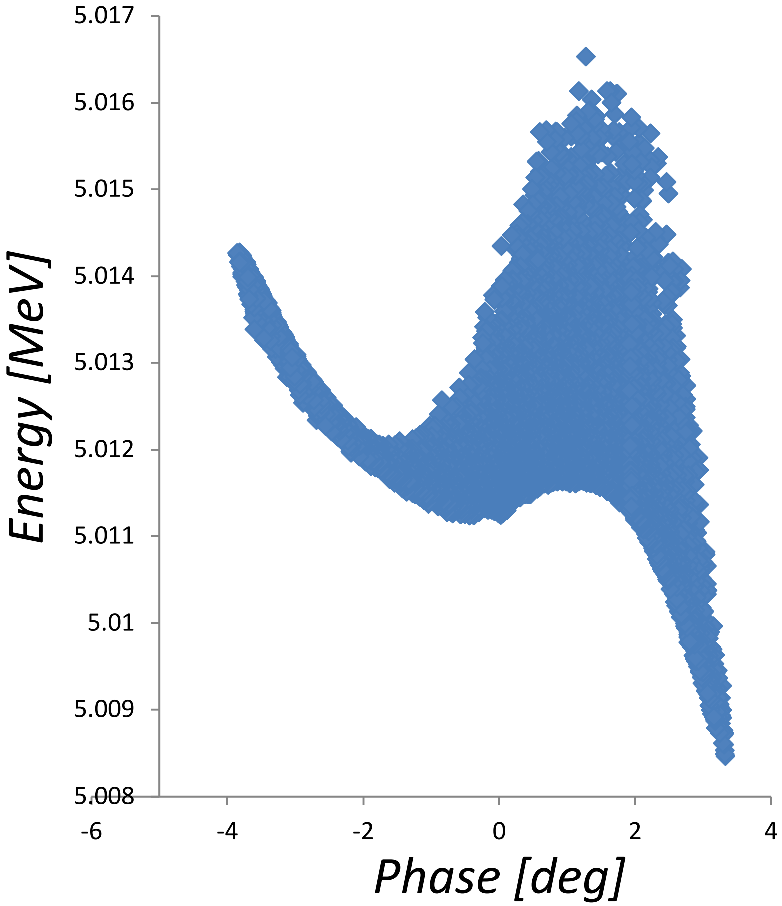
Goal: Find optimal combination of r_{56} and Φ_S for MESA 6-pass external beam mode

1. Import longitudinal phase space from MAMBO 150 µA simulation
2. Create randomized cavity parameters (4 cavities, $\Delta A_{rms} = 1 \cdot 10^{-4}$, $\Delta\phi_{rms} = 0.1°$)
3. For each pair of r_{56} and Φ_S track each particle through the accelerator

$$E_{i+1} = E_i + (A + \Delta A)\cos(\phi_S + \delta\varphi + \Delta\phi)$$

$$\varphi_{i+1} = \varphi_i + r_{56} \cdot \delta E / E_{ref} \cdot 156°$$

4. Calculate rms energy spread for each pair of r_{56} and Φ_S



Simulation by R. Heine

MESA: External Beam Operation

Results for 6-pass external beam mode:

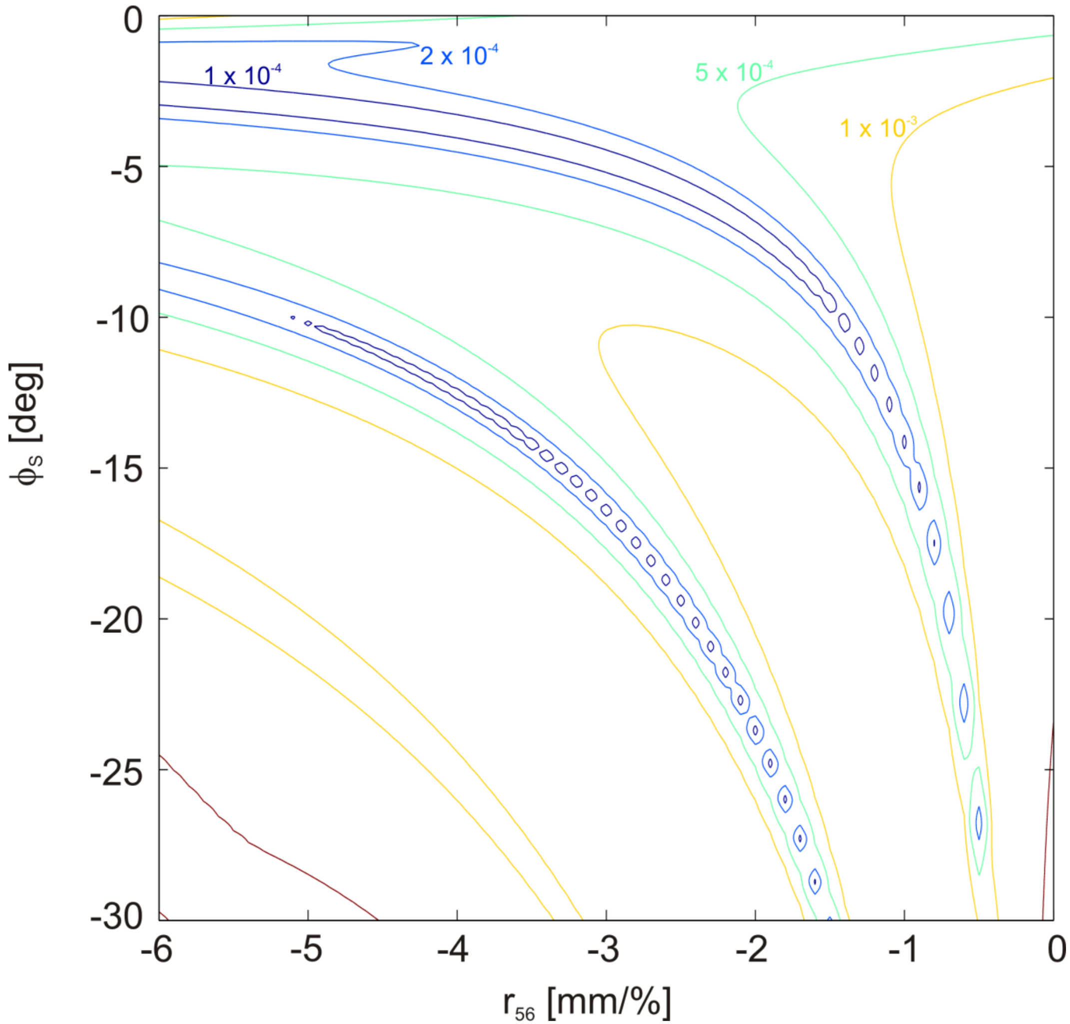
→ best energy spread at:

r_{56} = -2.6 mm/% and

Φ_S = -5.8°

$\Delta E_{rms}/E = 5.5 \cdot 10^{-5}$

isochronous: $\Delta E_{rms}/E = 3.4 \cdot 10^{-4}$

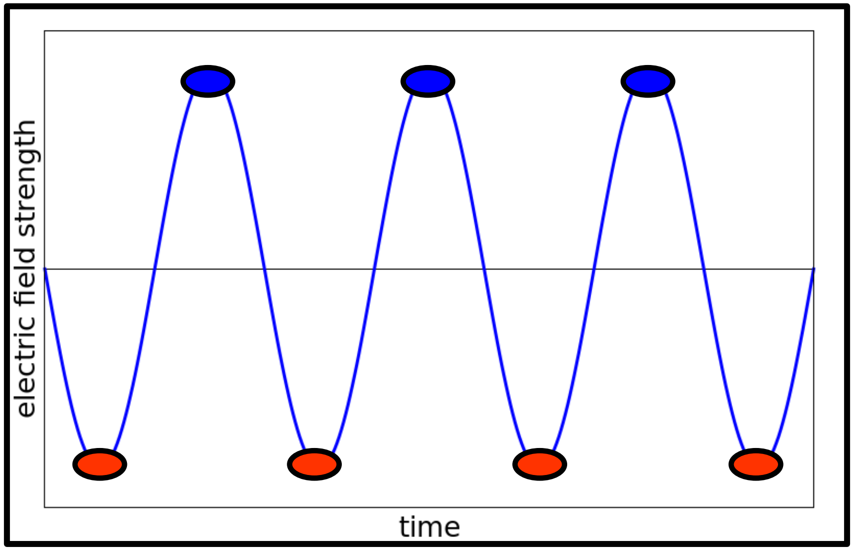


MESA: ERL Operation

Compare the two different ERL operation modes:

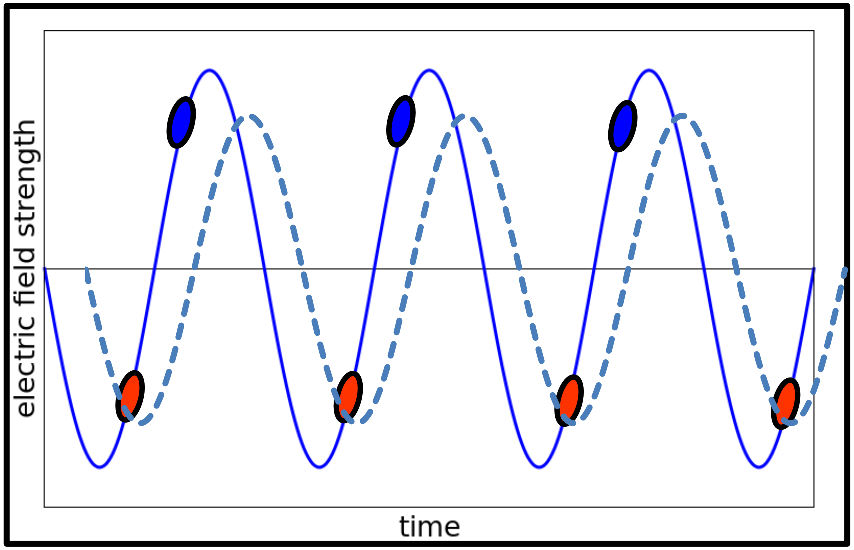
isochronous operation

Accelerating and decelerating bunches in phase with maximum/minimum of RF-field



non-isochronous operation

Decelerating bunches re-enter cavities at a different phase
→ disturbance on accelerating phase as well



→ On the non-isochronous working efficiency of energy recovery decreases
→ Maybe impossible for RF-control system to sustain desired accelerating field

Simulation results for isochronous ERL operation

- High space charge forces at maximum beam current → deformed bunches
- Resulting energy spread depends mostly on bunchlength → optimize for short bunches
- Bunches in the short bunch setting can be further compressed in the 180° injection arc

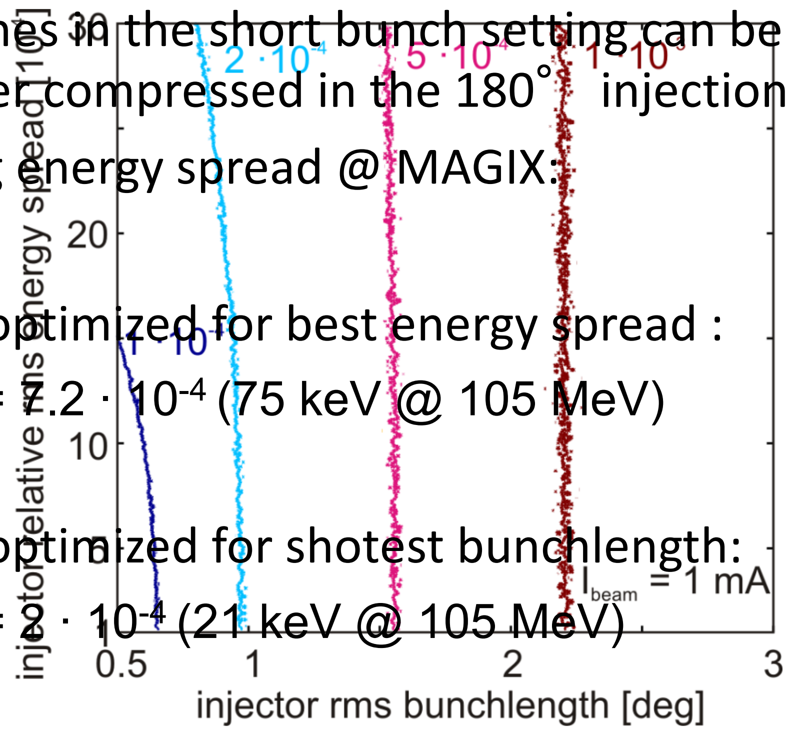
Resulting energy spread @ MAGIX:

Injector optimized for best energy spread :

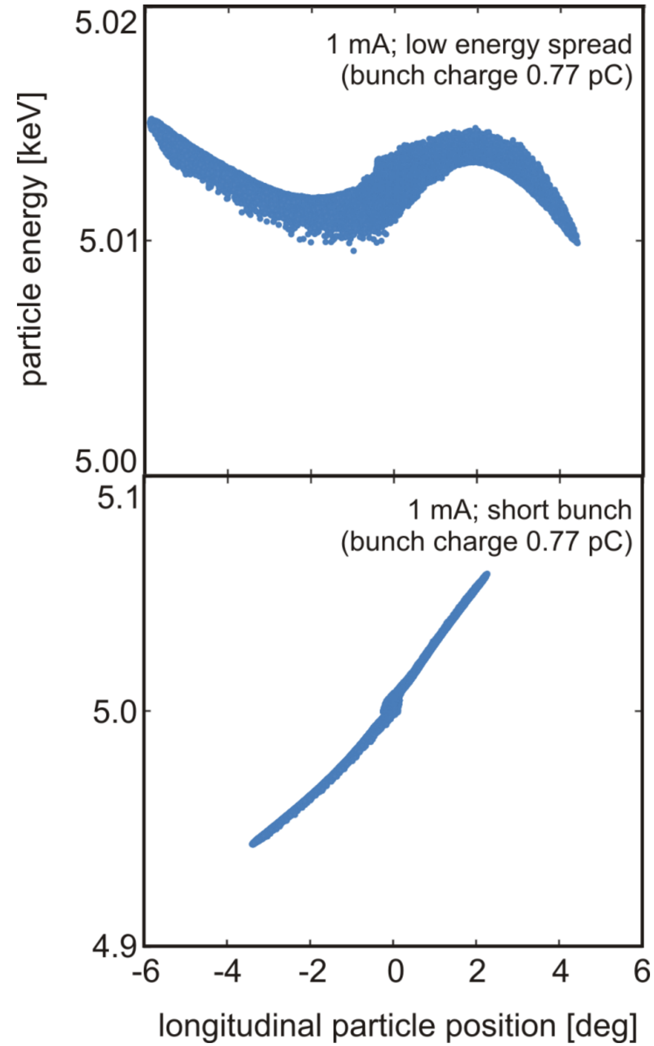
$\Delta E_{rms}/E = 7.2 \cdot 10^{-4}$ (75 keV @ 105 MeV)

Injector optimized for shotest bunchlength:

$\Delta E_{rms}/E = 2 \cdot 10^{-4}$ (21 keV @ 105 MeV)



Injector phase space

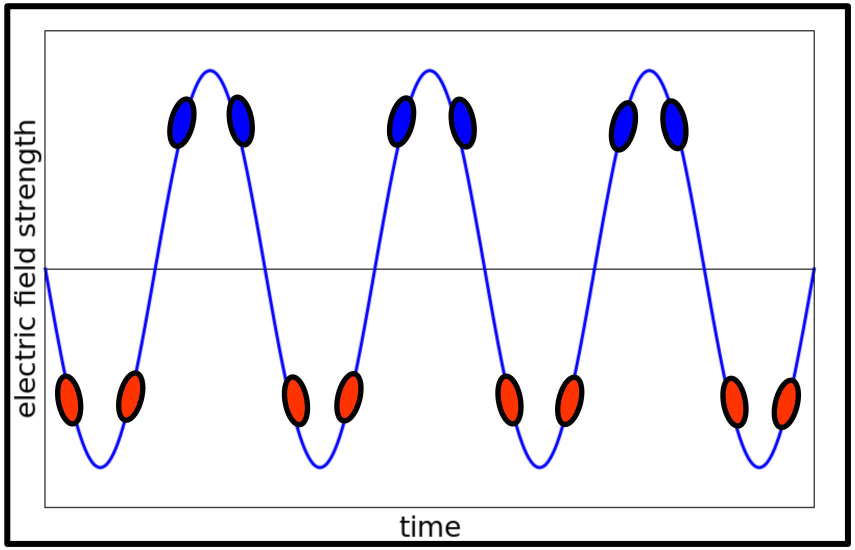


Simulation by R. Heine

MESA: non-iso ERL Operation

May be a different non-isochronous scheme in ERL operation possible?

- Use the double sided design of MESA
- First two passes acceleration off crest
- Use negative r_{56} for a half turn in phase space
- Second two passes acceleration off crest on **opposite** side
- Use positive r_{56} for a half turn in phase space (opposite direction)
- end up with better energy spread
- Deceleration vice-versa



First simulation results:

On crest, isochronous: $\Delta E_{rms}/E = 2 \cdot 10^{-4}$ (21 keV @ 105 MeV)
Off crest, non-isochronous: $\Delta E_{rms}/E = 8.9 \cdot 10^{-5}$ (9.3 keV @ 105 MeV)

Summary & Outlook

- MESA will be constructed in a double sided layout with vertical spreaders and vertically stacked return arcs
- two different operation modes (External Beam vs. ERL) and the requirement by the experiments for enabling every energy setting between ~20 MeV and maximum energy means a challenge for lattice design
- Lattice design is ongoing. Magnet design needs to follow. Start of accelerator construction is planned end 2020
- at MESA a non-isochronous recirculation scheme is planned in the external beam mode for providing best energy spread @ P2
- for ERL mode at MESA further investigations are needed in order to figure out the possibility of such a system

More about MESA at ERL 2017:

MESA experiments: Talk by K. Aulenbacher (FRIACC002)

MESA sources and photocathodes

- Halo measurements:	Talk by M. Dehn (MOIBCC002)
- K2CsSb photocathodes:	Poster by V. Bechthold (MOPSPP004)
- Polarized source STEAM:	Poster by S. Friederich (MOPSPP005)
- High current source SPOCK:	Poster by L. Hein (MOPSPP006)

MESA beam dynamics

- after internal target:	Poster by B. Ledroit(MOPSPP007)
- LEBT:	Poster by C. Matejcek(MOPSPP008)
- BBU in ERL operation:	Poster by C. Stoll (MOPSPP009)
- Microbunching instability:	Talk & Poster by A. Khan (THICCC002 & MOPSPP001)